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LIGHT AND YOUR EYES

A Lecture to Children

By S. S. BEGGS, M.A. *(Member)*, and W. R. STEVENS, B.Sc., A.M.I.E.E. *(Fellow)*.
(Research Laboratories of The General Electric Company, Limited, Wembley, England.)

(Presented at the Joint Meeting of the Illuminating Engineering Society and the Science Masters' Association, on Wednesday, April 17th.)

Introduction.

The first lecture to children arranged by the Illuminating Engineering Society was given at Christmas, 1943, at Bradford, by Mr R. O. Ackerley, a past president of the Society, and one of the authors (W.R.S.) of this paper. Since then similar lectures have been given in many different parts of the country, and the version below, containing much of the material used in the Bradford lecture, has been found to interest children as far apart as Leeds and Cardiff.

As reproduced the lecture is intended to serve two purposes. Firstly, it is intended to provide a talk lasting about one hour; more material than is necessary for a talk of this length has been included, and it is presumed that the lecturer will modify it according to the age of the audience. For example, in talking to children under fifteen we have usually omitted the experiments with a heated tungsten filament and with short-wave ultra-violet radiation. Secondly, it is thought that Science Masters may like to select some of the experiments for use in their ordinary school science courses.

We have found it useful, when giving the lecture, to concentrate on interesting the children rather than on obvious instruction. To this end we have always begun with a simple conjuring trick, making the point of how easily the eyes can be deceived.

We should like to acknowledge the co-operation of many bodies in the provision of equipment and illustrations for this lecture.

Light Sources.

It is hard to believe that 50 years ago gas mantles and electric lamps were almost unknown. Our fathers and mothers when they were children were happy if they were able to read by a gas flame, without any mantle; generally they would have to make do with paraffin lamps or candles. Since those days there have been many inventions and many changes in the science of making light and we are lucky to have very efficient lamps—lamps which produce much light at little cost. Let us spend some time in tracing the history of light sources and then we will consider how they help us to see well.

1. Early Sources of Light.

Years ago the only light which men could make came from the fires they lit to warm themselves and to frighten away animals. Torches of burning wood enabled primitive men to see their way about after the sun set, although I expect they generally preferred to stay in their caves. Then it was discovered that burning fat produced a bright light, and this principle was applied in one way or another to give artificial light for thousands of years. Even now we make use of this early discovery whenever we light a candle.

The oldest known oil lamp is thought to date from about 8000 B.C. It is simply a hollowed-out stone in which animal fat was burned. Fig. 1 shows a Roman lamp made about 600 B.C. Its design is simple, but other lamps were

Fig. 1. Roman lamp of 600 B.C.

Fig. 2 (right). Persian multiple wick lamp.

Fig. 4. Link-boys carrying torches. (17th Century.)

Fig. 5. Cartoon of lighting of Pall Mall, London, by gas lamps (1807).

much more elaborate. Fig. 2 is a Persian lamp in which several wicks floated, for it had been found better to get light from wicks soaked with oil than to set fire to the oil itself.

In time it was found possible to make lamps in which the oil was solid, namely candles, consisting simply of a twisted wick dipped into melted tallow. This form of lighting was very important to England in the Middle Ages, as you can see from a petition presented to the Lord Mayor of London by the Company of Tallow-Chandlers, shown in Fig. 3. In those days there was, of course, no street lighting as we know it to-day, and if you had to be out after dark and could afford it, you would employ a Link Boy (Fig. 4) to carry a light for you. Work that needed much light could not be done at night, and some of the old craft guilds would not even allow their members to work by night because such work might be poorly done.

2. GASLIGHTS.

Towards the end of the seventeenth century an interesting experiment was made by the Rev. Dr. John Clayton, who showed that by heating coal he could make a gas which would burn. It is very easy to do. Take a clay pipe and half-fill the bowl with coal dust: cover this with clay and heat it in a coal fire or over a bunsen burner. As the coal gets hot we shall see vapour coming from the stem, and soon this vapour will give place to an invisible gas, which burns brightly if it is lighted. (Expt. 1.)

Dr. Clayton's discovery was not made use of for a hundred years: but in 1792, William Murdoch lighted his house with coal gas, and this was the beginning of a great change in lighting. Gas companies were formed with the object of making gas on a large scale at central works so that the gas could be sent through pipes to wherever it was needed. Gas was used to light streets, and Pall Mall, in London (Fig. 5), was one of the first to be lighted in this way. There were no gas mantles in those days; the light came straight from a flame as it did in our clay-pipe experiment, and many different types of burner were used to get the best light. (Fig. 6.)

In their search for better light several people noticed that certain things became very bright if they were made very hot, but they were not satisfactory in a gas flame since they became covered with soot. However, in 1855, Professor Bunsen invented a burner which gave a very hot flame without much light, and this encouraged scientists to experiment with gas mantles. The final solution to the problem was found by Baron von Welsbach, who, by 1893, had made satisfactory mantles; even to the present day we use mantles very like those invented by von Welsbach.

To make a mantle it is necessary to knit a "stocking." Welsbach used cotton for this, but now we use either ramie fibre—the ramie plant grows in India and China—or artificial silk. The stocking is a long tube which can be cut into convenient lengths according to the type of mantle required. It must be cleaned thoroughly, and then it is soaked for a few minutes in a solution of thorium and cerium nitrates which are going to give light when heated. When the stocking is dried it is cut and made into mantles, complete with the clay ring by which the mantle will be fixed to the burner. Now comes the most interesting part of the whole process: a flame is applied to the mantle and all the original material of the stocking is burned away, so that what remains is a delicate skeleton of ash containing thoria and ceria. This ash is shaped like the original mantle, somewhat shrunk, and it has to be further heated to strengthen and finally shape it. The last process of all is to coat the mantle with a varnish to protect it until it is fixed to a burner. Fig. 7 shows

REASONS *humbly offered to the Right Honorable the* Lord Mayor, Aldermen, *and* Commons, *of the City of* London, *in* Common Council *Assembled, by the Company of* TALLOW-CHANDLERS *of the same City, against Setting up and Establishing the* Lamp-Lights *of any sort in this City, as varying from the antient Custom.*

THAT this Company have been Incorporated about 23. Years, and are now become a numerous Body; several of whom have been called to, and served in the greatest Places of Trust and Honour of this City, and have always assisted as well in Purse as Person to aid to its Grandure, and to the support of the present Government.

That this Company, with the whole City, being restored to their antient Privileges and Customs thought themselves safe from any other Invasion of their Laws, one of which is an Act of Common Council, made the 3. of *October* 1599. whereby every Housholder from the First of *October* to the First of *March* in every year for ever, should cause a substantial Lanthorn and a Candle of Eight to the Pound to be hang'd without their Doors.

That notwithstanding the said Act (but in force) certain unfree Men, who are not capable of serving any Office in any Company, nor Office of Trust within this City, neither chargable towards the support of the Grandure and Government of the same, have set up, and do continue in the Streets of this City and Liberties thereof, a great number of *Coarse Lamps* and other *Lucidaries*, in opposition to, and derogation of, the said Act, and to the manifest Injury of this and other Companies, in their lawful Trade.

That the aforesaid *Lamps* or *Lucidaries* are wrotely Novel, and should they be encouraged they will cause many more such Inventions upon other Arts and Mysteries, whereby the Labour and Industry of many Thousands may be lost, and their Families impoverished.

That the setting up and use of the said *Lamps*, within this City and Liberties, for the time past have been, and for the future will be a great Prejudice, if these New Lights obtain the Countenance of a Common Council.

First, To this Company, in taking away the Use of their lawful Trade, to which they have serv'd and taken many Apprentices, and made suitable provisions for carrying on their Trades, for the subsistence of themselves and Families; and that if the continuance of these Lamps be suffered, they will hinder the making and selling of Seventeen Dozen of Candles to every Lamp set up and used in this City and Liberties in every Year, and so much will be taken away from the maintenance of the *Tallow-Chandlers* and Families, and the support of their lawful and useful Trade.

And altho great annual Rents, and other Considerations may be offered to this City, by the Partners of the several New Lights, (and as they pretend) towards payment of the Orphans, yet nevertheless it's hoped, that not any of these New Lights will be Established for the sake of such Rents; and at the same time, by so doing, deprive the *Tallow Chandlers*, and other Trades in the Profits thereof, to a far greater value than the Profits of the Lamps can accrue unto the *Orphans*.

And to other Trades, as the *Hornters* in making of Leaves for Lanthorns for burning Candles in; *Tinmen*, and *Spinners* of *Cotton*, whereof the Twentieth part is not, nor cannot be used in Lamps, which is, and must be in Candles; and must necessarily deprive many Hundreds of Persons, (that live solely by these Trades), of their Maintenance and Livelyhood.

Secondly, That all Monopolies in all Ages have been esteemed Destructive, Oppressive, and against the Rights of the Subjects, and contrary to *Magna Charta*, and many other Statutes, and to the Common Law. And it was solemnly adjudged in the 44. *Eliz.* in *Coke's* 11. Report, in the case of Monopolies, and many other Cases. The same was so declared by Proclamation in the 1. of King *James* I. and by a Statute made in the 21. year of his Reign. *Cap.* 3. yet under a Proviso to grant Letters Patents to the first Inventors of new Manufactures for 14 Years, not contrary to Law, nor hurtful to the People, as may appear by the Paper or Reasons now in Print, and lately offered by this City to the Parliament, against their passing the Bill for granting a further Term to the Partners concerned in the *Convex Lights*, which Bill being put to the Question it passed in the Negative, as may appear by the Votes of that Honourable House on *Friday* the 30th of *December*, 1692.

It is humbly hoped, that Projects so pernicious to the publick Good of the Kingdom, and the private and lawful Trade of many Thousands of Their Majesties Subjects, who as the Law stands, have as great a Right as any other of Their Majesties Subjects have to their Trades, and the lawful Use and Advantages thereof, will not find or receive any encouragement from this City: And for that the Parliament would not give any encouragement to the Convex-Lights, *(as is humbly conceiv'd) in tenderness and regard to the Privileges and Customs of this City, so this Company a part of, and subject to, the Corporation of this City, may justly hope, they will not do any act to the prejudice of this Company, in relation to their said Trade.*

But that the Act of Common Council *for enlightning the Streets of this City with Candles in Lanthorns may be strictly observed, or that this Honorable Court will be pleased to make another Act, for the more strict and regular Observance of the Duty of Lighting the Streets of this City and Liberties with Tallow Candles in Lanthorns, which will be cheaper to the Inhabitants than any sort of Lamps.*

[By courtesy of the Tallow Chandlers' Company.

Fig. 3. Petition of the Company of Tallow Chandlers (17th Century).

the appearance of the fibres before and after burning, and Figs. 8 and 9 some of the raw materials and finished mantles. There are many shapes and sizes with which we are not all familiar, but they all convert heat into light for our homes, factories, and streets.

3. Electric Arc and Filament Lamps.

While von Welsbach and his fellow-workers were making such great improvements in getting light from coal gas, other people were experimenting with a completely different method of getting light from electricity. In 1810 Sir Humphry Davy had shown how a carbon arc lamp could produce light. He passed an electric current through two rods of carbon arranged so that their tips nearly touched. The current "jumped" across the gap between these tips and heated the end of one of the carbons so much that it produced an intense light. Arc lamps of a similar nature are used to-day where an intense light is required, for example in searchlights and cinematograph projectors (Fig. 10). But these are too powerful for most ordinary use, as well as being rather complicated, and so other ways of making light were tried. The first filament lamps came in 1878 and were like that in Fig. 11. These were made by Swan in England, and at about the same time Edison in the U.S.A. produced a rather similar lamp. Down the centre of the lamp is a thread of carbon which is heated by passing an electric current through it. The carbon glows brightly and so gives out light. It is found that if such a filament is burnt in the open air it wears out very quickly because it oxidises and disintegrates, so it is necessary to put it in a glass bulb from which the air has been removed. Carbon filament lamps were used for many years, and even now have some special applications; Fig 12 shows a modern carbon lamp.

The hotter the filament in a lamp the more light it will give, but also the shorter time will it last. So a search was made for better materials than carbon, materials which could be made hotter and yet would not disintegrate too quickly. The most successful substance was found to be tungsten, and this is still used. It was made into wire and put into an evacuated glass bulb: the long straight filament is bent into a zig-zag shape so that the lamp is not too large for convenience (Fig. 13). Such lamps were in common use in the early years of this century and were much better than anything previously made, but they were very different from the lamps we use to-day. In a modern lamp the glass bulbs are no longer evacuated in most lamps; instead they are filled with a gas such as argon, which does not attack the hot wire and which, by exerting a pressure on the wire, helps to prevent it from evaporating. This gas would cool a long zig-zag filament, so that, whatever way the lamp were turned, the upper parts would be hot and bright while the lower would be cool and dull. (Expt. 2.) To overcome this, the fine filament is coiled into a spiral, and sometimes that spiral is coiled again so that a magnified picture of a filament would look like Fig. 14. The result of this spiralling is that the coils of the filament help to keep one another warm; this also reduces the amount of electrical energy required by the lamp. We can show the effect of coiling a wire in keeping itself hot by an interesting experiment. Take a coiled filament and hold it at one end in a clip fixed to an insulated retort stand clamp. Hold the other end in a clip fixed to an insulated handle. Now connect a circuit so that a small current will pass through the wire making it glow dull red in a darkened room. Do not make the filament too hot or it will burn out completely because it is surrounded by air. As soon as the filament is glowing, stretch it gently; as it gets longer its brightness will fall. The energy it is consuming is the same as before but

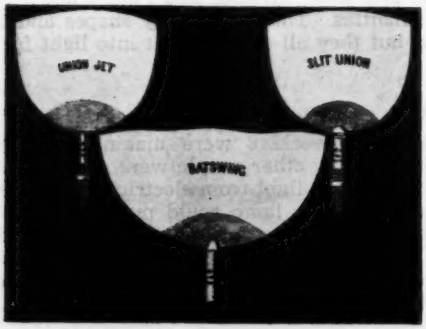
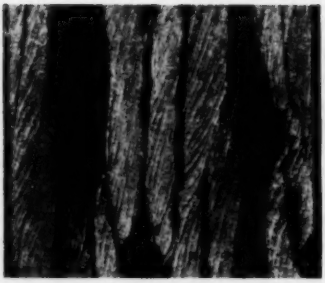
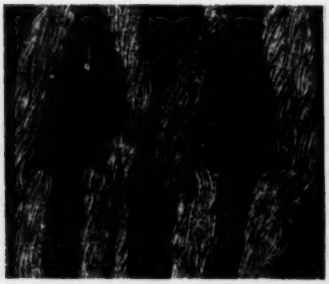


Fig. 6. Some typical burners for luminous gas flames (1890).

Fig. 7 (below). Prepared ramie mantle fabric. (a) Before and (b) after incineration.

(a)





(b)

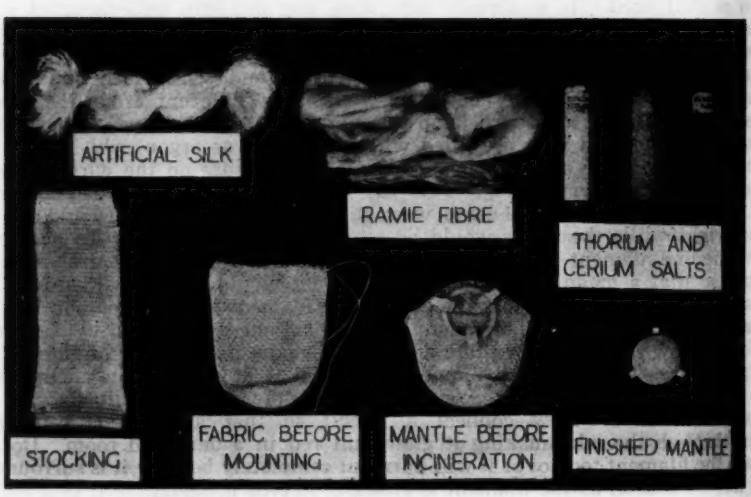


Fig. 8. Some stages in the manufacture of a gas mantle.

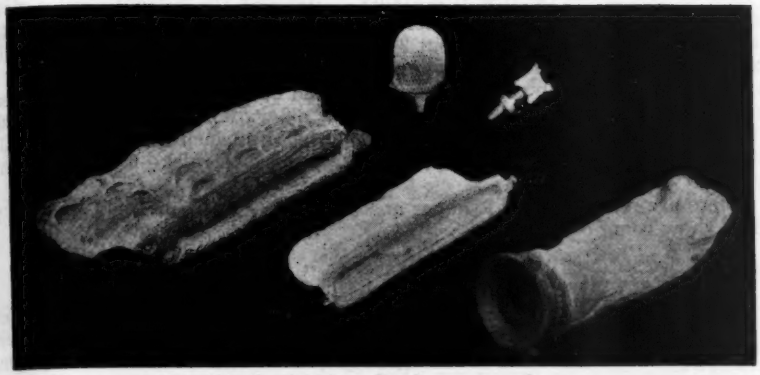
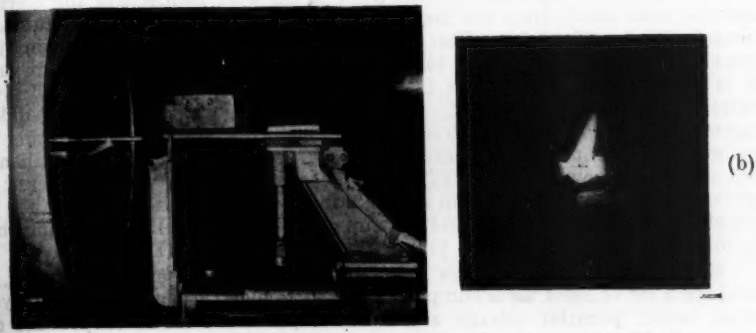


Fig. 9. A variety of modern gas mantles.



(a) (b)

Fig. 10. A modern carbon arc lamp, used for cinematograph projection. (a) The lamp, (b) the light source.

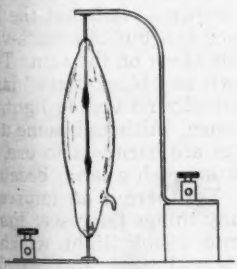


Fig. 11. Swan's original electric filament lamp. (1878).

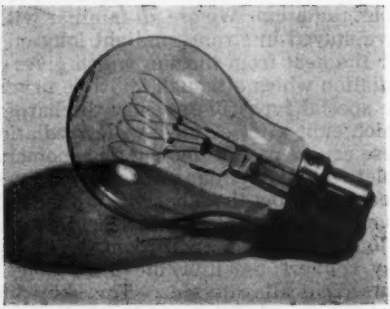


Fig. 12. Final form of carbon filament lamp.

its light output is less because it is cooler. Increase the current until it glows again, stretch it further, and once more it will cool. The filament, which started at about 1 in. long, will go to about 2 ft. before it breaks, if handled carefully. (Expt. 3.) It is interesting, also, to pull out a filament without any heating to get an idea of the length of wire which is coiled up, and to distinguish between the first and second coilings. (Expt. 4.) A 100-watt lamp for use on a 230v. supply has over a yard of wire 1.7 thousandths of an inch thick: in a 230v. 15-watt lamp the wire is only half a thousandth of an inch thick—finer than a hair from your head.

There are many different shapes and sizes of lamps made now and Figs. 15 and 16 show some of them.

4. Electric Discharge Lamps.

We see then that it is possible to produce efficient light sources by electrically heating a wire, and by passing a current between carbon rods; but there is still another way of making light electrically. We can obtain light by passing a current through a gas or vapour. Fig. 17 shows a mercury vapour discharge lamp, inside which can be seen an upper and a lower electrode. If an electric current is made to pass from one electrode to the other, through the lamp, a brilliant greenish light is emitted: there is no wire connecting the electrodes and the light comes from the mercury vapour with which the inner tube of the lamp is filled. (Expt. 5.) You have probably seen such lamps burning in the streets. Another lamp used for street lighting is filled with sodium vapour: it is different in construction from the mercury lamp (Fig. 18) and gives a yellow light. (Expt. 6.) It is interesting to see what effect these different lights have on colours and faces. In the sodium lamp light everything looks yellow or black: under the mercury lamp greens and yellows are brilliant but red does not show up well. This is because there is very little red light given out by the mercury lamp and red objects receive, therefore, no red light which they can reflect. The sodium lamp gives out only yellow light and objects in this light must reflect only yellow or nothing at all. (Expt. 7.)

Such discharge lamps have the value of being very efficient; that is, they produce a lot of light for a comparatively little electric power. But they give these rather peculiar colours and so attempts were made to produce other efficient lamps giving a nicer appearance. The method used involves an effect called fluorescence which we must consider in some detail.

We have seen that an electric discharge can be made to emit light. Such a lamp may also emit other forms of radiation, and one of these is called ultra-violet radiation. We are all familiar with one form of ultra-violet radiation if we have stayed in strong sunlight long enough to get brown. It is not the light nor the heat from the sun which gives our skin a nice tan, but this ultra-violet radiation which although invisible nevertheless has its effect on the skin. There are special types of mercury discharge lamps, known as "black-glass" lamps, which emit a lot of ultra-violet radiation with practically no visible light, and these can be used to show the phenomena of fluorescence. Although some ultra-violet radiation is dangerous to the eyes, these lamps are harmless to use. It is easy to show that there is no real light coming from such a lamp because a silver coin looks black when held near. (Expt. 8.) Yet there is an impression of light in the darkened room. This is because many things fluoresce; that is, they convert the invisible ultra-violet radiation into visible light which, of course, we all can see. The skin fluoresces, nails and teeth (not artificial teeth) shine a brilliant white, and if we look at the lamp we see a mist in our eyes due to fluorescence of the eyeball itself. (Expt. 9.) Vaseline or similar

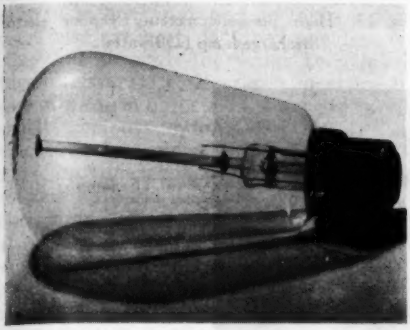


Fig. 13. Tungsten filament lamp of 'squirrel cage' vacuum type.

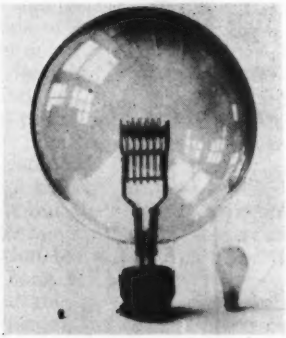


Fig. 16. Comparison of lamp sizes: torch bulb ($\frac{1}{4}$-watt), lighthouse lamp (10 kw), and household lamp (60 watts).

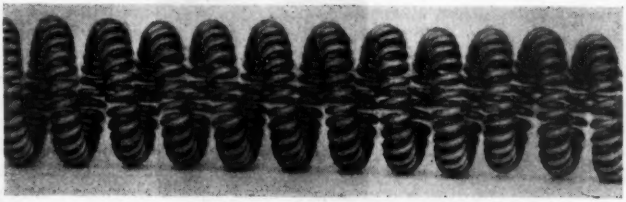


Fig. 14. Model of a coiled-coil filament.

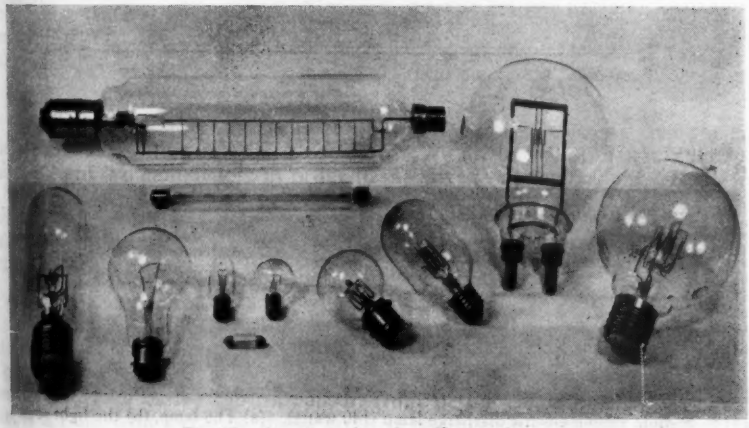
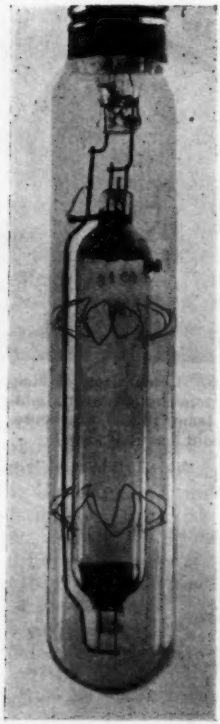


Fig. 15. A variety of modern filament lamps.

Fig. 17. High pressure mercury vapour electric discharge lamp (250-watts).

(a)



(b)

(a) The lamp.

(b) The light source.

(a)

(b)

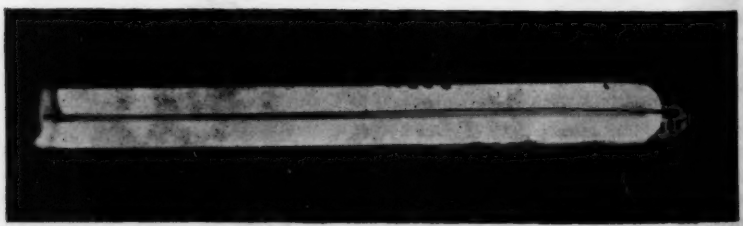


Fig. 18. Sodium vapour electric discharge lamp (140 watts). (a) The lamp, (b) the light source.

fatty material glows under the influence of the lamp. (Expt. 10.) Take a beaker of clean water and sprinkle a few crystals of fluorescein or eosin on top. These are both dark red powders which do not fluoresce when dry, but as they fall through the water they leave long fairylike streaks of green or orange. (Expt. 11.) Research workers have tried to improve on the fluorescence of natural objects and have made dyes and powders which give brighter and better colours under ultra-violet irradiation. Some of these are very complex chemicals such as zinc beryllium silicate, cadmium chlorophosphate, or magnesium tungstate, and their manufacture is a difficult process. Many of them look dull and uninteresting in ordinary light but they spring to life near a black lamp. (Expt. 12.) Others show the phenomenon called phosphorescence; that is, they not only convert ultra-violet radiation to visible light, but they also store up this energy and continue to glow long after they are removed from the lamp. If we take a card coated with suitably prepared zinc sulphide and cover it with an outstretched hand while exposing it to the lamp, we get, on removing it, a shadow picture of the hand which is rather amusing. (Expt. 13.)

There is another type of ultra-violet radiation to be obtained from a different mercury discharge lamp. It is dangerous to the eyes and in experiments with such a lamp it is wise to wear glasses, for the radiation will not pass through glass. This is easily shown by making a card fluoresce under such a lamp and then interposing a sheet of clear glass, which will cast a strong shadow on the card. (Expt. 14.) The materials which fluoresced under the previous lamp will not look very bright under this one, but there are other materials which react well. (Expt. 15.) It is these materials which are used in the fluorescent lamp shown in Fig. 19. This lamp gives a pleasant white light, very like that of a sunny day; and for a given amount of electrical energy it gives two to three times as much light as the electric lamps we use at home. (Expt. 16.) It is interesting to look at a lamp which is only half covered with fluorescent powder. For half its length—the uncoated half—the lamp gives a pale blue glow: there is no dangerous radiation coming from the lamp because the glass tube absorbs it. But there is ultra-violet radiation in the lamp, as we can realise by looking at the coated half. The fluorescent powder is coated on the inner wall: it picks up the radiation and, converting it to visible light, produces a bright, white appearance. (Expt. 17.) It is possible to produce many different colours in such lamps, for example red and green, and perhaps they will one day be used for decoration where coloured lights are required. (Expt. 18.)

The Eye and Vision.

Now that we know something of how light is made let us spend a little while considering how we make use of it. We all know, of course, that if we have no light we cannot see: in order to see we need enough light. How much is "enough" light? Can we have too much light? Does it matter about the colour of the light and the directions it comes from? We do not yet know the exact answers to all these questions, but we can easily learn a little about it for ourselves. To do this we must know something of how our eyes work.

5. Action of the Eye.

In many ways an eye is like a camera: Fig. 20 shows a comparison between an eye and a camera which is rather interesting. In the camera a lens forms a picture on a sensitive plate or film: in the eye a lens forms a picture on a sensitive surface called the retina. In front of the camera lens is a "stop"—that is a hole which can be made large if the light is poor and smaller if the

Fig. 19. The 80-watt (5 ft.) tubular fluorescent lamp.

Fig. 20. Comparison between the eye and a camera.

Fig. 21. Comparison of heights representing range of lighting intensities to which the eye responds.

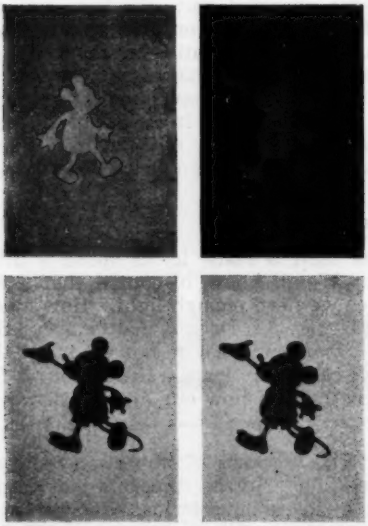


Fig. 22. Figures of different contrast.

THIS CARD IS INTENDED FOR USE BY PERSONS WITH NORMAL SIGHT TO CHECK SHOP-WINDOW LIGHTING. THE OBSERVER SHOULD STAND WITH HIS BACK TOUCHING THE WINDOW AND HOLD THE CARD ABOUT ONE FOOT FROM HIS
EYES. IF THE LIGHTING OF THE WINDOW IS AT THE APPROVED LEVEL, A PERSON WITH NORMAL SIGHT SHOULD JUST BE
UNABLE TO READ LINE , ALTHOUGH HE MAY BE ABLE TO READ LINES TO IF THE LIGHTING IS AT THE
SPECIALLY INCREASED LEVEL IT SHOULD BE POSSIBLE TO READ LINES TO BUT NOT LINE . THIS CARD IS
INTENDED FOR USE BY PERSONS WITH NORMAL SIGHT TO CHECK SHOP-WINDOW LIGHTING
THE OBSERVER SHOULD STAND WITH
his back touching the window
AND HOLD THE CARD
ABOUT ONE FOOT
FROM HIS EYES

Fig. 23. Reading chart of varying print size.

light is good: in front of the lens of the eye is the "iris" which opens wide in poor light and closes in a good light. We have already mentioned the sensitive plate in the camera. If we wish to photograph in a poor light, or to photograph a fast-moving object such as a train, we generally use a special plate which is very sensitive. We can in fact buy a whole series of plates, some more sensitive than others, to use according to the picture we are trying to take. The eye does much the same thing, but we do not have to put in a new retina every time we take a different picture: instead the retina changes itself. In a good light it is not so sensitive as in a dull light. So by closing the iris and reducing the sensitiveness of the retina the eye automatically adjusts itself to the amount of light.

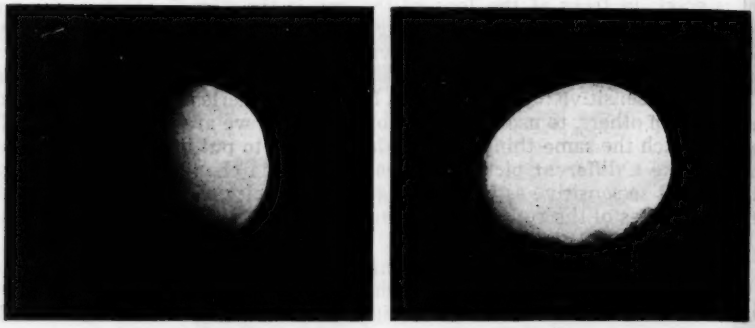
The range of light intensities to which the eye will respond is remarkable. If we represent bright summer sunshine by the height of Mount Everest (29,000 ft.), comfortable ordinary daylight might be represented by Snowdon (3,560 ft.), an ordinarily lighted room at home at night by the height of a man, a well-lighted street at night by a mole-hill, and full moonlight by the mole itself (Fig. 21). The eye, when given time to get used to any one of these, will work quite well and without discomfort; indeed, we can still see quite a lot if the moon goes behind a cloud, an amount of light represented by an ant. Yet Mount Everest is 10 million times as high as the ant.

Let us go back to the lens of the camera. This has to be adjusted when taking a picture according to the distance between the camera and the scene. We call it focusing the lens. The lens of the eye does the same thing: it focuses the object in which we are interested on to the retina. The lens of the camera must be moved by hand: the lens of the eye adjusts itself automatically and, as we look about, keeps changing from moment to moment, all day long, all the time the eyes are open. So you see the eye is a delicate thing and has to work hard: if you are wise you take great care of your eyes. Try not to overstrain them by working in a poor light, or when you are overtired. Wear glasses if you are told to do so, and keep them clean. Remember that there is no substitute for sight; and while you can walk with a wooden leg, or eat with false teeth, you cannot see with an artificial eye.

6. How Light Helps the Eye.

There is another point of resemblance between a camera and an eye which we have not mentioned: that is the time required to get a photograph and the time required to see. A camera will not take an instantaneous picture. It may do it in a very short time—say 1/1,000 second or less—but it is still a definite time: and the more light there is, the shorter the time required by the camera. In just the same way the eye does not record a picture instantaneously; it needs a fraction of a second in which to focus the picture and then send the message of that picture hurrying along the nerves from the retina to the brain. Like the camera, the more light we can give the eye, the quicker will it see. This can be shown by a simple experiment with a gramophone turn-table painted white on which six or eight radial spokes are painted black. Arrange to light the turn-table so that the amount of light can be altered quickly from dim to bright. Set the table turning until it is running at a steady speed with the dim light on. Quickly change to the other light and the disc will seem to slow down. Decrease the light and the disc will appear to go quicker again. The reason for this is that under the brighter light the eye sees more quickly and this makes the apparent speed less than with the dimmer light. (Expt. 19.)

There are many other experiments to show that you see better as the amount of light is increased. For example, let us look at a number of pictures



(a) (b)

Fig. 24. Object seen under (a) strongly directional lighting, and (b) general lighting.

such as those shown in Fig. 22, in which the contrast between the drawing and the background is gradually increased. In a dim light most of the sheets appear blank and only the figure of greatest contrast is visible. With more light some of the other pictures appear, and with plenty of light even the faintest becomes visible. (Expt. 20.) Thus plenty of light enables your eye to see objects which were not visible in a dim light; although you thought you could see all there was on the sheets in the dim light, your eye was deceived. In another simple experiment, the chart of Fig. 23 can be used, by keeping it at a fixed distance from the eye and altering the amount of light on it. You will find that under a poor light you cannot read such small print as under a good one, and your ability to pick our detail is increased with more light. (Expt. 21.)

It is important to have the light in the right place, that is on the thing at

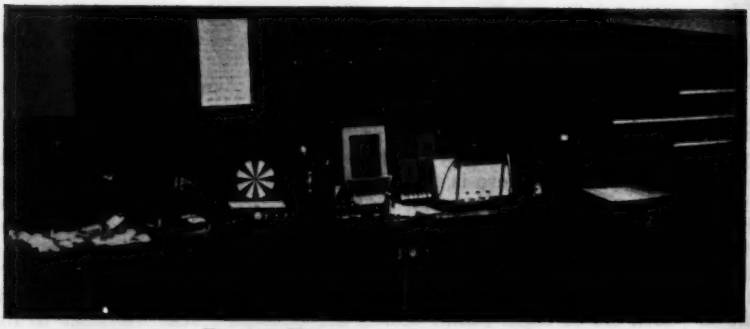


Fig. 25. Typical array of demonstrations.

which you are looking. If there is a lot of light shining into your eyes from somewhere else it will not help at all. The iris will get smaller and the retina less sensitive: the light is glaring and the eye does not like it. You can show this with the same picture (Fig. 23) as used in the last experiment. Hold the page so that as you read it a nearby lamp is just seen round the edge of the page: the lamp is glaring without lighting the paper. Move the page so that the

lamp is covered and then uncovered. You will find it more comfortable when you cannot see the lamp than when you can: in fact the lamp may even prevent your reading a row of type which you could read before. (Expt. 22.) It is important, therefore, not only to have enough light but to be sure that there is not a lot of glare. Glare may come either directly from lamps or from reflections in shiny surfaces: both sorts of glare are to be avoided.

The direction from which light comes, and the way in which it reaches the object at which we are looking are important. Things which look smooth with one form of lighting may look rough with another. Things which look round may turn out to be some other shape. In Fig. 24 (a), for example, we see what appears to be a white ball, such as a table-tennis ball; in Fig. 24 (b) we see something different. They are really the same object photographed, without being touched, from the same position. The lighting has been altered and has made the difference: Fig. 24 (b) shows the true shape. (Expt. 23.) So it is not just the amount of light which affects how well we see, but also the way the light is used. The quality of light is often as important as its quantity.

An important quality which we must remember is colour. We have already seen that sodium and mercury vapour lamps give light which distorts the appearance of things. This does not always matter; for example in lighting a street we generally need not worry too much. But for some things it is important to have properly coloured light. If we wish to match two paints or pieces of cloth it will not do to have a light which distorts their colour. On the stage a great many tricks are played by using mixtures of different colours. You may have seen, and been puzzled by, one in which a white-skinned person is suddenly changed to black, perhaps with their clothes changing at the same time. It is done by painting the face red and lighting with red light at first. The red face reflects the red light and looks very bright: the eye is deceived into thinking the face is white. Suddenly the light is changed to green: the red face cannot reflect green light and so it appears black. The clothes are altered in a similar way. (Expt. 24.)

7. CONCLUSION.

So we see that the eyes, wonderful as they are, can be deceived in many ways: and they can easily be made to work harder than they need because they are not cared for. If we are sensible we look after our eyes—which we can do without being finicky—and one way in which to help is always to use a good light for your work and play.

APPENDIX

Notes on Experiments

(A lay-out of the demonstration equipment used by the authors is shown in Fig. 25.)

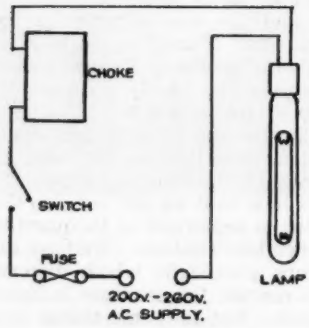
GENERAL NOTE.

Some of the demonstration material is of rather a specialised character, not generally available. However, it may be possible to obtain these articles on loan from organisations associated with the lighting industry.

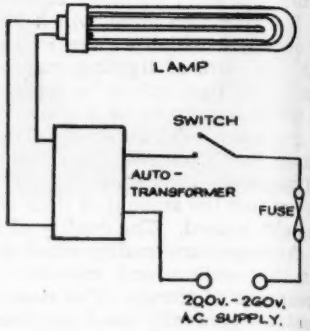
Expt. 1.—If a clay pipe is not available a tin with a hole in the lid or a hard-glass test-tube can be used; but the clay pipe is probably most convenient for handling.

Expt. 2.—See General Note. The lamp should either be mounted so that it can be turned at different angles while alight, or held in the hand. Darkening of the room is advantageous, but not essential.

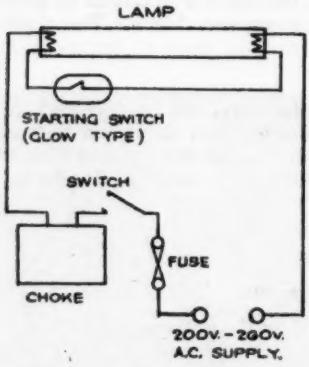
Expt. 3.—See General Note. A voltage about one-sixth that of the normal rating for the filament will be required to make it glow initially. As the filament is stretched the necessary voltage will increase to about half the normal rating.



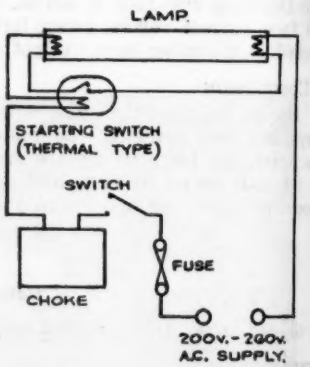
(a) High Pressure Mercury Vapour Lamp.



(b) Sodium Vapour Lamp.



(c) Tubular Fluorescent Lamp, with Glow Starting Switch.



(d) Tubular Fluorescent Lamp with Thermal Starting Switch.

Fig. 26. Circuits for demonstration of electric discharge lamps on A.C. supply.

in five or six steps. Use a sliding resistance arranged as a potential divider, or a Variac, of suitable rating. Allow for filament current at least equal to its rated value. Do not make the filament too bright, or it will burn out. The stretching should be done gently and steadily, avoiding jerks. (An assistant is useful.)

Expt. 4.—See General Note. As the filament will be invisible to the audience, get an assistant to hang small paper riders on the wire, to show its presence and indicate clearly when it breaks. With care in stretching, this will be when it is about 30 times its original length.

Expt. 5.—See General Note. The lamp must be wired in series with its appropriate choke on 200v.-260v. A.C. (Fig. 26(a)), or suitable ballast resistance on D.C. The 250-watt lamp is a convenient size (running current about 2 amps.; starting current approx. 50 per cent. greater). It *must* be burned vertically, but may be mounted cap downwards. As it requires four or five minutes to run up to full brilliancy, it should be covered by a metal canister and switched on at the beginning of the lecture. (It will not restart immediately if accidentally switched off when run up.)

Expt. 6.—See General Note. The usual type of lamp must be wired in circuit with its appropriate transformer on 200v.-260v. A.C. (Fig. 26(b)). It cannot be run on ordinary D.C. mains supply (250v. and less). The 140-watt lamp is suitable for comparison with the 250-watt H.P.M.V. lamp (current 0.9 amp.). This lamp should be burned horizontally. As 10 to 15 minutes are required for it to run up, it also should be covered by a metal canister and switched on at the beginning of the lecture. (Note: The open-circuit voltage of the transformer is of the order of 450 volts.)

Expt. 7.—If the H.P.M.V. and sodium vapour lamps are placed together with an opaque screen between them, the effects of the different lights on the coloured chart can be compared easily by transferring the chart quickly from one side of the screen to the other. It is as well to show the chart under filament lamp lighting first, so that it can be seen in its "natural" colours.

Expt. 8.—See General Note. An 80-watt "black glass" H.P.M.V. lamp (in series with appropriate choke on A.C. (Fig. 26(a)) or ballast resistance on D.C.) should be used in a reflector, screening the lamp from the audience. These lamps require a few minutes to run up, so should be switched on well in advance. (Make sure they do not irradiate fluorescent materials for later demonstration during this stage.) The table cover and background should be dark, non-fluorescing material to produce the best effect in all demonstrations of fluorescence.

White paper usually fluoresces sufficiently to provide a light background to the silver coin, which appears black (as the metal does not fluoresce). If a penny be held alongside a half-crown, they will appear indistinguishable.

Expt. 9.—Turn the lamp and reflector so as to irradiate the audience, and get them to look at their own and their neighbours' features. This causes much amusement.

Expt. 10.—Ordinary vaseline fluoresces brilliantly. A roughened surface is more impressive than a smooth one.

Expt. 11.—See General Note. Only a very small quantity of chemical is required; it is advisable to tip a few grains on to a sheet of paper beforehand for use in the lecture. They are strong dyes, and care should be taken not to let them get on clothing, etc. First show the dry chemical under the black lamp; then tip it on to the surface of water in a beaker irradiated by the lamp. Let the grains slowly sink, and finally stir them up to obtain the best effect.

Expt. 12.—See General Note. Show the chemicals under an ordinary filament lamp first, e.g., a reading lamp. Switch this out and quickly transfer the powders to irradiation from the "black" lamp. The increase in brilliance is striking. (Do not let any of the u.v. radiation fall on the chemicals beforehand.)

Expt. 13.—See General Note. Remove the hand and card together from the region of irradiation of the black lamp; then take the hand off the card, when its

"shadow" remains behind. The "shadow" can be washed out by holding the card (bare) again in the u.v. radiation from the lamp.

Expt. 14.—See General Note. A low-pressure mercury vapour discharge in a quartz tube (fed from a high tension transformer) is probably the most convenient source, although a carbon arc lamp emits this short-wave u.v. radiation also. Care must be taken to shield the eyes (of the audience and lecturer alike) from direct irradiation, as it may give rise to conjunctivitis. A sheet of clear glass placed on the audience side of the lamp (which should be housed in a deep reflector) is a sound precaution; the lecturer may have a similar sheet on his side or wear goggles.

The card of fluorescent material must first be placed to receive the radiation from the lamp direct; then a sheet of clear glass should be interposed between it and the lamp. If it shields only part of the card, the shadow will be more striking.

Expt. 15.—See General Note. Place under the lamp of Expt. 14 first the chemicals which fluoresced so brilliantly under the "black" lamp, and then those which respond to the short wave u.v. radiation: these must be in quartz or other u.v. transmitting containers, or may be poured out into watch glasses.

Expt. 16.—See General Note. The lamps at present available are 5 ft. in length, rated at 80-watts and 4 ft. rated at 40-watts. (Lower wattage lamps of shorter length will be available in the near future.) As with the other mercury vapour discharge lamps, each must be used in series with the appropriate choke on a 200v.-260v. A.C. supply, or with a suitable ballast resistance on D.C. supply; and each requires a starting device (Fig. 26(c) or (d)). Two "colours" of lamp are made, daylight and warm white. (The former matches daylight approximately, and the latter is roughly intermediate in colour between daylight and incandescent filament light.) Either may be used for this demonstration.

Expt. 17.—See General Note. Such a lamp is made only for purposes of demonstration. It requires the same electrical circuit as the normal tubular fluorescent lamp. (See Expt. 16.) As these low pressure lamps attain full brightness almost immediately they may be switched on or off as required.

Expt. 18.—See General Note and notes on Expts. 16 and 17. A wide range of colours is possible, using different fluorescent powders.

Expt. 19.—The disc should be divided into 12 to 16 sectors, alternately black and white, and should be rotated at a speed of about 70 r.p.m. (Trial will show the optimum speed for a given set of conditions.) The illumination on the disc should be 5 to 10-f.c. for the low level and should be increased to about five times for the high level. (The values are not critical.)

An alternative arrangement is to stand centrally on the turn-table a cylinder of about 6-in. diameter, on which letters or black and white vertical bands have been painted. The turn-table can then be used horizontally, which may be more convenient.

The low level of illumination on the turn-table may conveniently be that due to the ordinary room lights. The rapid increase in light is most easily attained by switching on a local light (say a 60-watt lamp) shielded from the eyes of the audience.

Expt. 20.—The pictures may be simple drawings in white chalk on black paper, or they may be figures cut from sheets of grey paper of differing shades, pasted on a dark background. (They should be broad outlines, not involving fine detail.) The illumination required for visibility depends on the distance of the observer and on the contrasts used. It should start very low, at about 0.1-f.c., and be increased in steps of about times three to the order of 10-f.c. (say a 60w. lamp in a box at a distance of 3 feet from the diagrams). The variation can be done by using a local lamp (possibly the same as that of Expt. 19) in series with a rheostat, of which the full resistance is approximately equal to that of the lamp used (at normal rating); this is of the order of 1,000 ohms for a 230v. 60w. lamp. Or a potential dividing device, as in Expt. 3, can be used.

Expt. 21.—Use the lamp and rheostat of Expt. 20 to illuminate the chart. A decrease

in illumination to one-tenth will suffice; this requires only half the full resistance of the rheostat to be used. Start with the lower illumination for preference.

Expt. 22.—A small lamp which can be switched on or off at will should be placed close beside but slightly behind the chart. Show the chart with the glare source switched off first; then switch the glare lamp on. Repeat once or twice.

Expt. 23.—A pot egg can be supported more easily than a real one. The directional lighting is provided by an ordinary torch. Make sure no light coloured surfaces are near or they may reflect light on to the shadowed side and reveal the shape; your hand is sufficient to do this, so it is advisable to wear a dark glove on the hand holding the demonstration. As the relative position of object and light is somewhat critical it is best to fix both on a stand, which can be held up and turned round as one unit for the audience to see the apparent ball. Black velvet is useful for preventing unwanted reflections. When the room lights are switched on the true shape of the egg becomes apparent.

Expt. 24.—A coloured picture may be used, but a real person (prepared beforehand) makes the demonstration more effective. (The explanation should *follow* the demonstration.)

In a picture the face should be coloured red on a green background. It is essential that the pigments should be of relatively pure hues; ordinary paints are not usually sufficiently selective. If a person is used, No. 2 Carmine grease paint should be applied over the whole of the face and neck visible on a base of cold cream rubbed well in. (This can be wiped and then washed off easily afterwards.) Brightly coloured clothing adds to the effect. Gloves may be worn on the hands. The colour-screens over the lamps have to be truly complementary; ordinary red and green stage gelatines are not satisfactory, but suppliers of stage equipment can supply suitable colours. Switch rapidly from one colour (the red first) to the other. (A two-way switch is useful for this purpose.)

Additional Experiments.

Many other experiments will suggest themselves, especially where only part of the above discourse is being used, but in greater detail.

Several experiments on gas are described in a book entitled "Lessons on Gas," produced by the British Gas Council; and the automatic gas lighter forms an interesting demonstration when discussing catalysis.

Demonstrations of radiation phenomena are innumerable; and fluorescence lends itself to spectacular magic. An experiment of special interest to older students is the demonstration of resonance absorption of short-wave u.v. radiation from a mercury vapour discharge by mercury vapour. If a little mercury in a watch glass is gently warmed and then placed near the lamp of Expt. 14 above, the clouds of invisible vapour will cast strong shadows on the fluorescent card.

DISCUSSION

Dr. W. D. WRIGHT said this was a type of lecture which, whilst being of great interest and real value to science masters, was also not without its interest to illuminating engineers. It was a happy expression on the part of Mr. Stevens when he spoke of "elevating" his audience to the status of youngsters. The fact was that when giving a lecture to children one usually gave a very much better lecture than when speaking to adults. Perhaps the outstanding example of this was the excellent talks which the B.B.C. include in their Schools Broadcasts. Certainly the lecture that evening was also a very good one for adults and especially for those who did not know much about lighting. In lecturing to schoolboys and schoolgirls, we might hope to encourage them to take a general interest in scientific phenomena, which was admirable, and also get some of them so enthusiastic about lighting that they would become desirous of being illuminating engineers. The profession of illuminating engineering was rather peculiar in that one rarely set out to become an illuminating engineer in the first place, so that it should perhaps be pointed out to boys

that they must study physics, chemistry, electrical engineering, and so on, before they could become illuminating engineers. One thing Mr. Stevens said interested him. He asked his audience to sit back and enjoy the lecture and take no notes—admirable advice, but a little unfair, because I have no doubt that school masters usually asked their boys to write an essay on the lectures which Mr. Stevens had given them. Perhaps it would not be a bad idea if the science masters present went home and wrote an essay on what they had heard that evening!

Mr. A. E. MacKenzie said the lecturer had made the principles of teaching seem very simple and clear, but he doubted whether many science masters could emulate the conjuring trick with which Mr. Stevens had started. As a teacher he had tried to carry out some of these demonstrations and he had picked up quite a number of little tricks in listening to this lecture, but, unfortunately, the equipment used by Mr. Stevens was not available to the ordinary school lecturer.

Mr. G. H. Wilson thought it might be possible for the Society to arrange for a certain amount of lecturing equipment of this type which could be loaned to science masters, although it might not be quite so complete as that used by Mr. Stevens. The Society could also be of value to science masters in another way. In text books where there was a chapter on lighting there was usually no reference to recommended values of illumination, and many science masters must be quite in the dark about that. He therefore suggested that the Society should circulate to science masters, through the Science Masters' Association, a list of the recommended values of illumination for various purposes. The science master's job involved a compromise between cultural teaching and utilitarian teaching, but lectures of this type from experts helped considerably to solve their problem.

Mr. L. F. Ennever (hon. secretary, Science Masters' Association) expressed appreciation of the enormous amount of trouble that had been taken in preparing this lecture. He also emphasised the point that science masters could not stage such demonstrations as they had seen that evening, but added how valuable it was to watch these matters put over by an expert.

Mr. C. E. Greenslade thought it would be valuable if they were told whether any of the pieces of apparatus used during the lecture could be borrowed, because most of them were not easily obtainable. Indeed, some of the lamps used would be very valuable in illuminating school laboratories. The use of ultra-violet light in science lectures in school always proved extremely interesting, and he recalled an instance in which one of the girls had some make-up under her eyes which, under the influence of fluorescent lighting, made them show up a brilliant blue, causing a great deal of laughter on the part of the other students.

Mr. Ashurst expressed appreciation that this joint meeting had been arranged, and recalled the great success of the previous one held two years ago. He expressed the hope that there would be many more such joint meetings between the Illuminating Engineering Society and the Science Masters' Association.

Mr. E. C. Lennox referred to lectures that had been given to school children

of about the age of 15 in the area of his supply company, and said that the success of these lectures had resulted in many more requests coming in from the school authorities. He suggested the desirability of having a further lecture which would cover, in simple language, lighting in the home and lighting in the streets, indicating how to recognise good and bad features of such lighting.

Mr. H. S. ALLPRESS. (*Communicated.*) I suggest that in spite of remarks by previous speakers, it should not be forgotten that the paper by Mr. Stevens and Mr. Beggs is presumably primarily intended as a spectacular demonstration for use on special occasions. It should, therefore, be borne in mind that for normal teaching purposes it is frequently inadvisable to include too many demonstrations on one occasion, as otherwise the value of the lesson to be learned from each experiment may be very largely lost.

In the case of science and engineering students who, it must be remembered, do not attend lectures just for amusement but to obtain the requisite information for the passing of examinations, I have found it desirable to allow time to develop each experiment to the level of the particular syllabus concerned and make sure this is fully understood before passing on to the next.

Taking, for example, the demonstration of the pulled out tungsten filament, more can be made of this demonstration if, instead of a flimsy filament, a piece of nickel-chrome wire (such as an old radiator element) is threaded on a piece of asbestos string and supported between two retort stands. If the wire is pulled straight, leaving the spiral only in the centre, and sufficient current is passed, the central portion reaches appreciably higher temperature. This apparatus is more substantial, and the experiment need not be hurried. Furthermore, since the same current passes through both spirals and the plain wire the reduction in heat losses of the former is proved.

With the same apparatus it is also possible to demonstrate that the increased efficiency of the modern filament lamp is dependent upon filament temperature. To do this a wattmeter is connected in the circuit, preferably with a luminous pointer. It can then be shown that an appreciable power can be absorbed in the wire without the emission of any visible light and that, by increasing the temperature, the light output (as shown by photo-electric set-up) rapidly increases. It can be shown that the light output per watt is greatly increased at the higher temperatures.

Mr. S. S. BEGGS, replying to the discussion, said the primary object of the lecture was to interest children in light in the home and school, and not to encourage them to become illuminating engineers, although that might come later on. It was also intended to make children realise the need for taking care of their eyes and how this could be done. So far as science masters were concerned, it was desired to help them as much as possible, although the lecture that evening, as on previous occasions when it had been given, had been primarily arranged for the children. It was fully realised that as given that evening the lecture included too much for a class lecture; but it was hoped that science masters would be able to pick up many hints and, as a result, arrange individual experiments from the notes given in the appendix for the purpose of their ordinary class lectures. The series of experiments described was far from exhaustive of the subject, and could obviously be varied both in substance and presentation. A number of books on the general subject were available which would also considerably help science masters in preparing their lectures and demonstrations. Some equipment for demonstrations might

become available through E.L.M.A., or through the British Gas Council. Nothing had yet been arranged, but he thought it would be a great help if some gear were made available in this way, as obviously the resources of a school were not sufficient for the purpose. Regarding follow-up lectures as suggested by Mr. Lennox, he thought care should be taken not to get too scientific when dealing with children. In this particular lecture the use of too scientific terms had been avoided as far as possible, with the idea of the lecture being suitable for children between the ages of 14 and 17.

I.E.S. Convention

Publication of Papers and Addresses

It has already been announced that the various papers and addresses delivered at the I.E.S. Convention, the titles of which appeared in the souvenir programme, are to be published in full in a coming brochure.

This brochure is to be issued separately from the Transactions, but with the same size of page, so as to be uniform for binding if desired.

It is thought expedient, however, that at least the full titles of these papers and addresses should be on record in the Transactions. In what follows we accordingly give a complete list of titles and authors together with the date of delivery:—

Author.	Title.	Date of Delivery.
(a) Papers and Addresses:—		
Professor H. HARTRIDGE, M.A., M.D., Sc.D., F.R.S. (*Member*).	Recent Advances in the Physiology of Vision.	15th May
PERCY GOOD, C.B.E., F.C.G.I. (*Fellow*).	The I.E.S. and War-time Problems.	15th May
L. J. DAVIES, M.A., B.Sc. (*Member*).	New Lamps for Old.	15th May
W. R. STEVENS, B.Sc., A.M.I.E.E. (*Fellow*) and J. M. WALDRAM, B.Sc., F.Inst.P (*Fellow*).	Laboratory Techniques in Solving War-time Visibility Problems.	16th May
S. ENGLISH, D.Sc., F.Inst.P., M.I.E.E. (*Fellow*).	Some Developments in Airport Ground Lighting.	16th May
W. ALLEN, B.Arch., A.R.I.B.A. (*Member*).	Daylight and Town Planning.	16th May
W. J. JONES, M.Sc., M.I.E.E. (*Fellow*).	Fluorescent Lighting Practice.	16th May
(b) Popular Talks:—		
R. A. ESHELBY (*Member*).	Lighting in Captivity.	14th May
CRAWFORD SUGG (*Member*).	Some Light on Invasion.	14th May
H. R. RUFF (*Member*).	Some Uses of Black Light.	14th May
J. S. PRESTON, M.A., F.Inst.P., A.M.I.E.E. (*Fellow*).	Conjuring with Colours.	14th May

THE EFFECT OF NON-UNIFORM REFLECTANCE OF THE INTERIOR SURFACE OF SPHERICAL PHOTOMETRIC INTEGRATORS

By H. BUCKLEY, D.Sc. *(Fellow)*

The theory of the integrating sphere as developed in the text books assumes that the reflection factor of the inside of the sphere is everywhere the same. It is easy to paint the inside of the sphere so that the reflection factor is constant over its area, but in use the sphere gradually becomes darker. It probably becomes darker in two ways, one due to a general reduction in reflection factor with age of the paint (often a slight yellowing of the paint); the other a dirtying of the lower hemisphere, which increases towards the bottom. This dirtying is largely due to the deposition of dust, some of which seems to stick to the paint, which in order to be as completely diffusing as possible is usually matt and so easily becomes dirty. Dusting the sphere with a duster or brush tends to damage the paint slightly and to lower its reflection factor. The final result is that a time arrives when the bottom of the sphere appears noticeably darker than the rest and a decision has to be made about repainting it.

Different designs of spheres will show different rates of darkening. The 10-ft. sphere at the N.P.L. has over it a platform on which operators of the sphere can walk about. It also has, at the top, a number of annuli which can be taken out and replaced in order to introduce fittings of various sizes. It also has a side door through which a horizontal platform like a diving board can be introduced and on which operators can enter the sphere to perform adjustments inside.

If all the light sources that are compared in the sphere had the same polar distributions of light the effect of dirt on the sphere would not matter, as it would affect the observations made on the light sources under test to the same extent that it affected the standard light source with which they are compared. When different light distributions are compared in a dirty sphere the effect of the dirt is not the same in the two cases, and the operator has to decide whether the sphere paint is sufficiently uniform or not. The decision is usually taken on subjective grounds, based on past experience with the sphere in a dirty state and after being repainted. Experience seems to show that the effect of dirt is not very serious, but no analysis has been made of the effects likely to be produced. It is the purpose of this note to calculate the effect which can be produced in the comparison of light sources having different polar distributions under different laws of darkening of the sphere.

The problem of the integrating sphere is one of the inter-reflection of light. Problems of this sort have been shown by the author to lead to integral equations, which in most cases only lead to approximate solutions. In the case of the sphere the integral equations usually lead to simple solutions, which can, however, also be obtained by other methods.

The integral equations result from the expression, in mathematical terms, of the fact that, at any point x, in a diffusely reflecting enclosure, the final illumination, $E'(x)$ due to a light source in the enclosure, is made up of the first incident illumination, $E_1(x)$ from the light source, together with the reflected illumination from the rest of the enclosure. It will be assumed that the light source is so small that it reflects no light back to the walls of the enclosure.

Thus if

$E'(x_1)$ = final illumination at any point x_1

$E_1(x_1)$ = first incident illumination at any point x_1

$\phi(x,x_1)dS_x$ = illumination at x_1 due to an element of area dS_x at x when the illumination at x is unity.

$\rho(x)$ = reflection factor at any point x

Then $$E'(x_1) = E_1(x_1) + \int_s \rho(x)E'(x)\phi(x,x_1)dS_x$$

where the integration is carried out over all the areas dS_x which enclose the point x_1.
For the sphere it can be shown that $\phi(x,x_1) = 1/4\pi r^2$
Hence for a sphere of unit radius

$$E'(x_1) = E_1(x_1) + \frac{1}{4\pi}\int_s \rho(x)\ E'(x)dS_x$$

i.e. $$E'(x_1) - E_1(x_1) = \frac{1}{4\pi}\int_s \rho(x)\ E'(x)dS_x$$

The right hand side of the above equation is independent of x_1; it is therefore constant and equal to K_1

Hence $$\frac{1}{4\pi}\int_s \rho(x)\ E'(x)\ dS_x = K_1$$

Substituting for $E'(x)$ under the integral sign its value $E_1(x) + K_1$ it follows that

$$\frac{1}{4\pi}\int_s \rho(x)\ E_1(x)dS_x + \frac{K_1}{4\pi}\int_s \rho(x)dS_x = K_1$$

but $\frac{1}{4\pi}\int\rho(x)dS_x = \bar{\rho}$ = the average reflection factor over the sphere.

Hence $$\frac{1}{4\pi}\int_s \rho(x)\ E_1(x)dS_x = K_1(1 - \bar{\rho})$$

so that $$E'\frac{1}{4\pi(1-\bar{\rho})}\int_s \rho(x)E_1(x)dS_x = K_1 = E'(x_1) - E_1(x_1)$$

In the usual use of the integrating sphere a small diffusing glass window is placed at x_1 with a small screen between it and the light source, so that the first incident illumination at x_1 is cut out. Thus, in these circumstances, the illumination at x_1 is given by $E'(x_1) - E_1(x) = K_1$ and the brightness of the outside of the window given by τK, where τ is proportional to the transmission factor of the window.

If a second light source takes the place of the first then the brightness of the window is given by τK_2 and

$$\frac{K_2}{K_1} = \frac{\int_s \rho(x)\ E_2(x)dS_x}{\int_s \rho(x)\ E_1(x)dS_x}$$

If $\rho(x)$ is constant everywhere and equal to $\bar{\rho}$, the usual condition with a uniform sphere and $L_2 = L_1$

then $$\frac{K_2}{K_1} = \frac{L_2}{L_1} = 1$$

If $\rho(x)$ is not constant then

$$\frac{K_2}{K_1} = \frac{\int\rho(x)E_2(x)dS_x}{\int\rho(x)E_1(x)dS_x} \neq 1$$

The effect of the dirty sphere has been obtained by determining the value of K_n/K_1 for a number of light distributions at the centre of a sphere when $\rho(x)$ is not constant, where K_1 refers to the standard light source taken as a point source. These different distributions $C_n(\theta)$, shown in figs. 1 to 6, are symmetrical about a

vertical axis. The variation of the reflection factor is also taken as symmetrical about a vertical axis. Coordinates are taken in terms of the angles from the vertical axis, the downward direction being 0°. Each of the distributions $C_n(\theta)$ is such that the total lumen output from the distribution is 4π, i.e., for each distribution

$$2\pi \int_0^{\pi} C_n(\theta) \sin\theta \, d\theta = 4\pi$$

The variation in reflection factor is expressed

as $\rho(\theta) = r_1 - (r_1 - r_2)\cos 2\theta, \quad 0 < \theta < \frac{\pi}{4}$

or as $\rho(\theta) = r_1 - (r_1 - r_2)\cos^2\theta, \quad 0 < \theta < \frac{\pi}{2}$

where r_1 is the reflection factor of the undirtied portion of the sphere and r_2 that of the bottom of the sphere where $\theta = 0$. These two cases correspond to

(1) a gradual falling off of the reflection factor from r_1 where $\theta = 45°$ to r_2 where $\theta = 0$,

and (2) a gradual falling off of the reflection factor from r_1 where $\theta = 90°$ to r_2 where $\theta = 0$.

In the latter case the falling off of reflection factor is confined to the lower hemisphere and in the former to a zone of angular width of 45° around the bottom. Table I gives the mathematical formulation of the various distributions together with the value of the first reflected flux under the two laws of variation of reflection factor of the interior surface.

TABLE I.

Distribution	1st reflected flux $\rho(\theta) = r_1 - (r_1 - r_2)\cos 2\theta$	1st reflected flux $\rho(\theta) = r_1 - (r_1 - r_2)\cos^2\theta$
(1) $C_\theta = 1$	$4\pi \{ r_1 - 0.0691 (r_1 - r_2) \}$	$4\pi \{ r_1 - (r_1 - r_2)/6 \}$
(2) $C_\theta = \frac{4}{3} \left(0 < \theta < \frac{\pi}{2}\right)$ $= \frac{2}{3} \left(\frac{\pi}{2} < \theta < \pi\right)$	$4\pi \{ r_1 - 0.0921 (r_1 - r_2) \}$	$4\pi \{ r_1 - 2 (r_1 - r_2)/9 \}$
(3) $C_\theta = \frac{2}{3} \left(0 < \theta < \frac{\pi}{2}\right)$ $= \frac{4}{3} \left(\frac{\pi}{2} < \theta < \pi\right)$	$4\pi \{ r_1 - 0.0461 (r_1 - r_2) \}$	$4\pi \{ r_1 - (r_1 - r_2)/9 \}$
(4) $C_\theta = 4 \cos\theta$ $\left(0 < \theta < \frac{\pi}{2}\right)$	$4\pi \{ (r_1 - 0.25 (r_1 - r_2) \}$	$4\pi \{ r_1 - (r_1 - r_2)/2 \}$
(5) $C_\theta = \frac{4}{\pi} \sin\theta$ $(0 < \theta < \pi)$	$4\pi \{ r_1 - 0.0125 (r_1 - r_2) \}$	$4\pi \{ r_1 - (r_1 - r_2)/8 \}$
(6) $C_\theta = 14.47 \cos 2\theta$ $\left(0 < \theta < \frac{\pi}{4}\right)$	$4\pi \{ r_1 - 0.6450 (r_1 - r_2) \}$	$4\pi \{ r_1 - 0.8262 (r_1 - r_2) \}$

Table II gives the value of K_n/K_1 for the different distributions under the two laws of variation, viz.,

$$\rho(\theta)=0.80-(0.80-r_2)\cos 2\theta \qquad 0<\theta<\frac{\pi}{4}$$

$$\rho(\theta)=0.80-(0.80-r_2)\cos^2\theta \qquad 0<\theta<\frac{\pi}{2}$$

for values of r_2 of 0.60 and 0.70

These correspond to an initial reflection factor of 80% which has deteriorated so that at the bottom of the sphere it is 60% or 70%

TABLE II.

n Distribution	K_n/K_1			
	$\rho(\theta)=0.80-(0.80-r_2)\cos 2\theta$		$\rho(\theta)=0.80-(0.80-r_2)\cos^2\theta$	
	$r_2=0.60$	$r_2=0.70$	$r_2=0.60$	$r_2=0.70$
(1) $C_\theta=1$ $(0<\theta<\pi)$	1.000	1.000	1.000	1.000
(2) $C_\theta=\frac{4}{3}\left(0<\theta<\frac{\pi}{2}\right)$ $=\frac{2}{3}\left(\frac{\pi}{2}<\theta<\pi\right)$	0.994	0.998	0.986	0.994
(3) $C_\theta=\frac{2}{3}\left(0<\theta<\frac{\pi}{2}\right)$ $=\frac{4}{3}\left(\frac{\pi}{2}<\theta<\pi\right)$	1.006	1.003	1.015	1.008
(4) $C_\theta=4\cos\theta$ $\left(0<\theta<\frac{\pi}{2}\right)$	0.954	0.978	0.913	0.958
(5) $C_\theta=\frac{4}{\pi}\sin\theta$ $(0<\theta<\pi)$	1.014	1.008	1.011	1.006
(6) $C_\theta=14.47\cos 2\theta$ $\left(0<\theta<\frac{\pi}{4}\right)$	0.853	0.927	0.828	0.916

Distributions 2 and 3 are fairly representative of fittings of the semi-direct and semi-indirect class, distributions 1 and 5 of the "general" class (B.S. Spec. 398). It will be seen that for all these the value of K_n/K_1 differs from unity by less than about 1½%. It is only for distributions 4 and 6, which are extreme examples of the "direct" class, that the effect may become serious. In the photometry of these distributions, either a sub-standard of similar distribution should be used, or the measurements carried out in a fairly clean sphere.

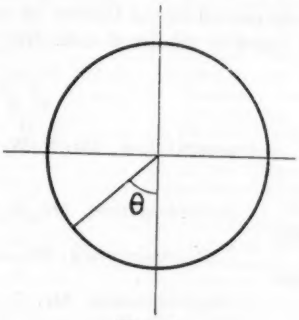


FIG. 1.

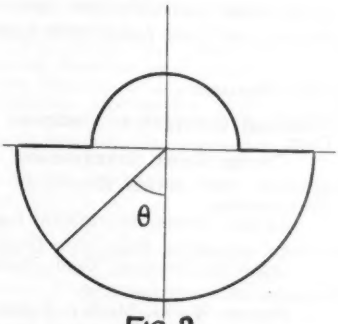


FIG. 2.

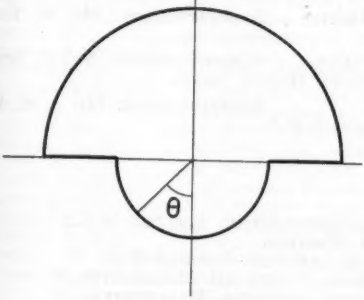


FIG. 3.

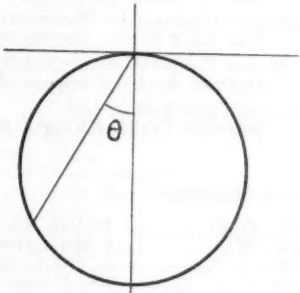


FIG. 4.

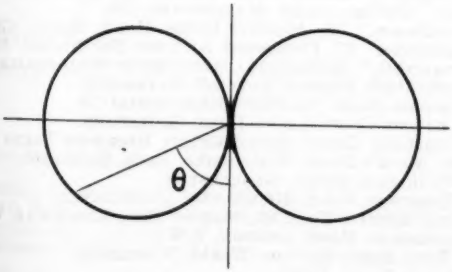


FIG. 5.

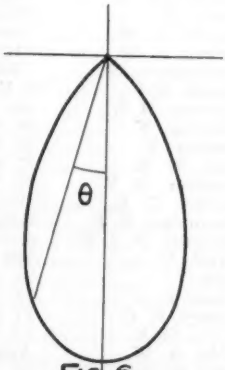


FIG. 6.

Additions to List of Members.

The following applicants have been duly elected by the Council to membership in the Society, and their names have been added to the list of members:—

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Wingate, R. P. .....Room 112, Lighting and Heating Dept., North Eastern Electric Supply Co., Ltd., Carliol House, NEWCASTLE-UPON-TYNE.
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TRANSFER TO CORPORATE:—

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The Annual General Meeting

The annual general meeting of the Illuminating Engineering Society took place in the Lecture Theatre of the Institution of Electrical Engineers, Victoria-embankment, London, at 10.0 a.m. on Wednesday, May 15, 1946.

The Secretary read the notice convening the meeting and also the statement of the auditors for the past year.

The President, presenting the Report of the Council and statement of accounts for 1945, said members would agree it was a record of a very satisfactory year. No fewer than 266 new members had been admitted, bringing the membership up to 1,853 at the end of the year. Two Groups were given Centre status and the record of meetings throughout the year was very satisfactory. The financial position disclosed in the accounts was also very satisfactory, and it had encouraged the Council to embark on the Convention as being a fitting culmination to the wartime activities of the Society and the inauguration of what everybody hoped would be a long period of peace in which the Society would continue to flourish and prosper.

Adoption of Report and Accounts

The following resolution was then put to the meeting by Mr. C. I. Winstone and seconded by Mr. H. C. White:—

> That the Report of the Council and the accounts of the Illuminating Engineering Society for the period January, 1, 1945, to December 31, 1945, be hereby adopted, and that a vote of thanks be extended to the President, Council and officers for their efforts on behalf of the Society during the past year.

On being put to the meeting the Report was declared carried unanimously.

The President, on behalf of the Officers and Council, expressed his appreciation of the vote of thanks. It was a very great pleasure to them all to serve the Society as well as they had been able, and he regarded the vote of thanks as also including those members of the Council who had retired to whom a debt of gratitude was also due. For his part he wished to pay tribute to the work of the Headquarters staff for their loyal service during the year under review.

On the proposal of Mr. L. H. McDermott, seconded by Mr. K. R. Mackley, Messrs. Robert Ward and Co., were unanimously re-elected as auditors of the Society.

Election of Officers and Council

The president said that as regards the officers and members of the Council there had been no independant nominations, and therefore the Council's nominations stood. Those elected were as follows:—

President: Mr. J. S. Dow.
Vice-Presidents: Mr. J. M. Waldram, Mr. N. V. Everton, Mr. J. S. Preston.
Hon. Treasurer: Mr. Percy Good.
Hon. Secretary: Mr. H. C. Weston.
Members of Council: Mr. C. J. Alldridge, Mr. L. J. Davies, Mr. C. E. Greenslade, Prof. T. David Jones, Mr. T. S. Jones, Mr. E. W. Murray, Mr. A. J. Pashler, Mr. A. G. Penny, Mr. W. R. Stevens, Mr. F. Walker, Dr. E. C. Walton.

This terminated the formal business.

Presentation to Honorary Secretary

A presentation, consisting of a travelling clock, a wrist-watch, an attaché case, an illuminated address, and a cheque was then made to the retiring honorary secretary, Mr. J. S. Dow. The president and Sir John Herbert Parsons (past president), in making the presentation, spoke in high terms of Mr. Dow's services to the Society since its initiation in 1909. Mr. Dow, in expressing warm thanks for the kind thought that had prompted this generous gift, paid a tribute to the ungrudging efforts made on behalf of the Society by its members —to which the success of the present Convention was due.

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